Elastic J/ψ production at HERA

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14th International Workshop on Deep Inelastic Scattering

April 20-24, 2006, Tsukuba, Japan

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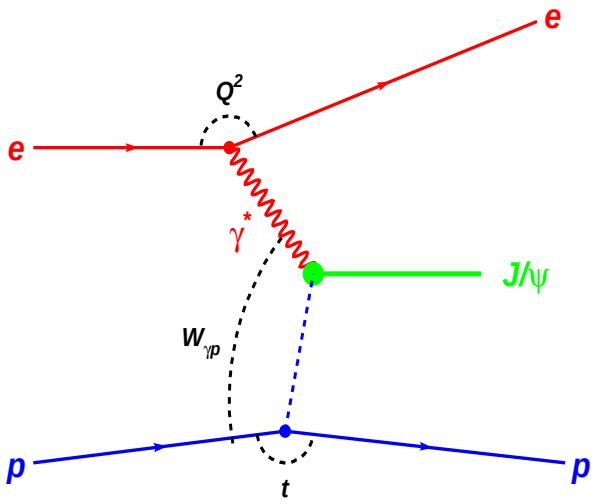
- **Results**
- **Summary**

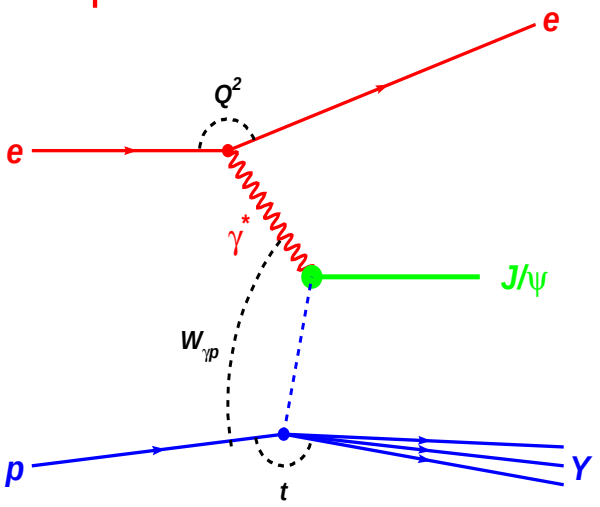
Introduction

Diffractive Vector Meson Production

elastic



proton dissociative



Q^2 : Photon Virtuality

Photoproduction: $Q^2 \sim 0$

Electroproduction: $2 < Q^2 < 80$ GeV^2

t : (4-momentum transfer)^2 at p vertex $0 < |t| < 1.2$ GeV^2

Proton dissociates: large $|t|$

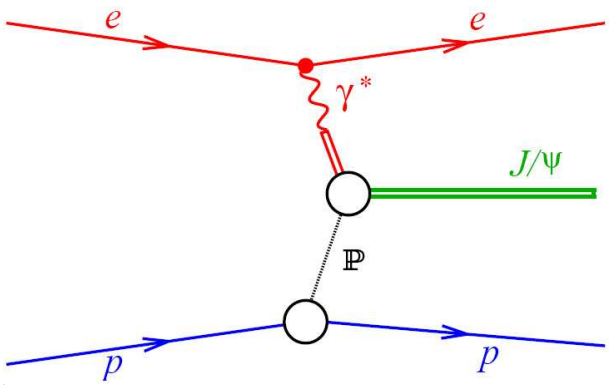
W : CM-energy of γp system

Photoproduction: $40 < W < 305$ GeV

Electroproduction: $40 < W < 160$ GeV

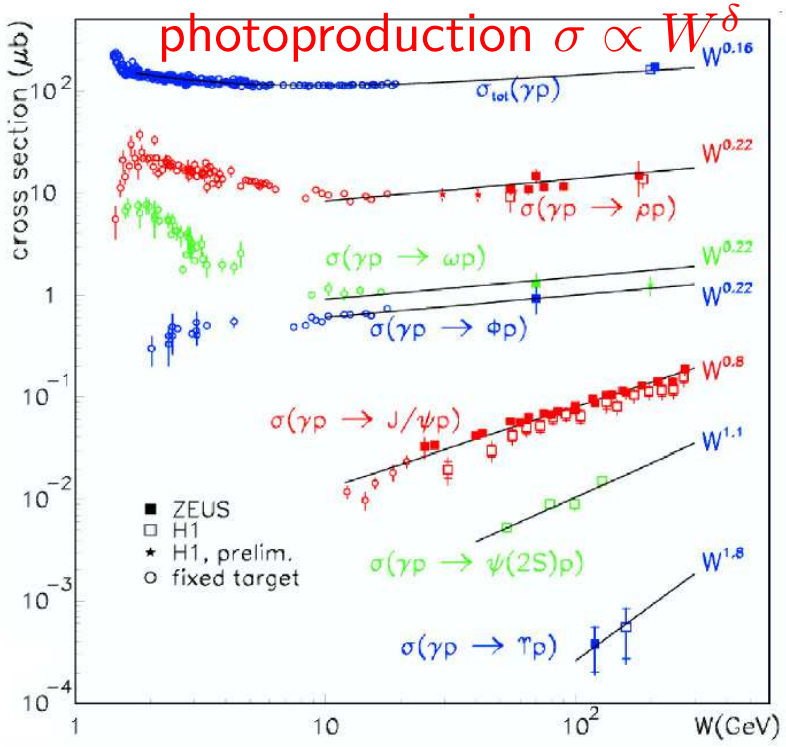
Diffractive Vector Meson Production Models

Regge Model:



- Soft Pomeron exchange
  $\alpha_P(t) = \alpha_{P0} + \alpha'_P \cdot t$
- Slow rise of σ with increasing W
  $\sigma \propto W^{0.22}$
- Shrinkage
  $\frac{d\sigma}{dt} \propto e^{bt}$, $b = b(W_0) + 4\alpha'_P \cdot ln(\frac{W}{W_0})$
- S-channel helicity conservation (SCHC)

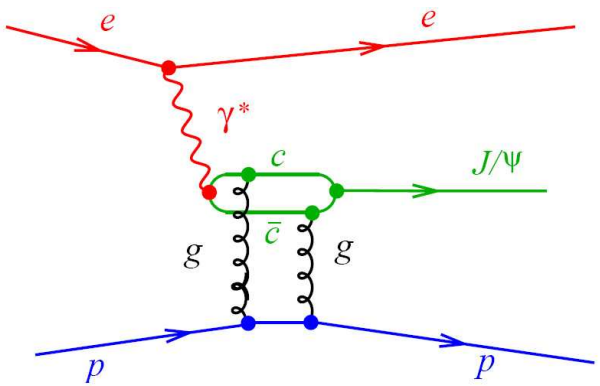
photoproduction $\sigma \propto W^{\delta}$



- ρ, ω, ϕ show Regge behaviour
  $\sigma \propto W^{0.22}$
- J/ψ is not described by Regge
  $\sigma \propto W^{0.80}$

Increasing M^2_{VM}:
Regge-Model $\longrightarrow$ pQCD Model

pQCD Model:



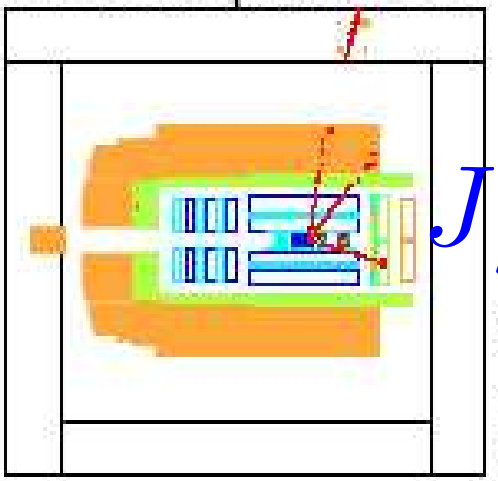
- Exchange of at least 2 gluons
- Steeper rise of σ with increasing W
  $\sigma \propto [x \cdot g(x, Q^2_{eff})]^2$,
  $x = 4Q^2/W^2$, $Q^2_{eff} = (Q^2 + M^2_\psi)/4$
- No or weak shrinkage

pQCD needs hard scale: Q^2, M^2_{VM}, t

- MRT (Martin, Ryskin and Teubner)
  - skewed gluon distribution (x $\neq$ x′)
  - parton-hadron duality approach
  - predicts W and Q^2 dependence
- FMS
  (Frankfurt, McDermott, Strikman)
  - skewed gluon distribution
  - dipole approach
  - predicts W dependence

Data Analysis

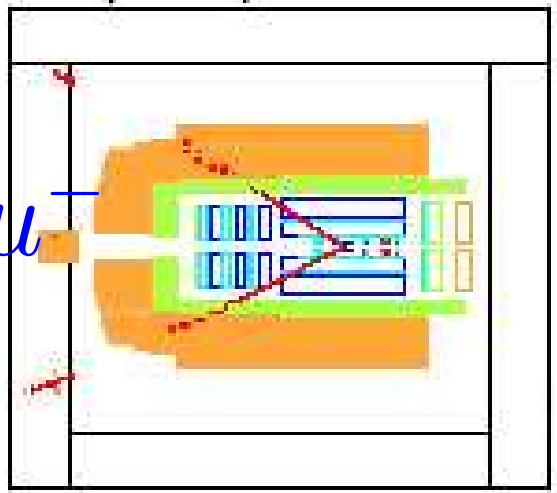
TT electroproduction



$J/\psi \rightarrow \mu^+\mu^-$

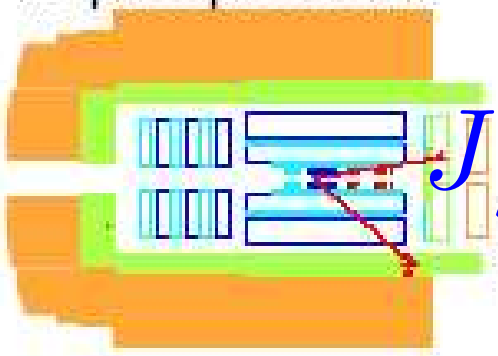
2 tracks
≥ 1 muon
scatt. positron

TT photoproduction



2 tracks
≥ 1 muon

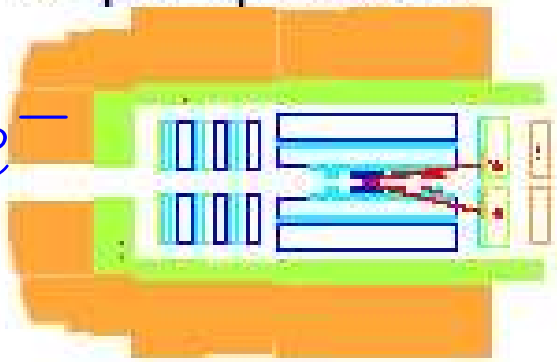
TC photoproduction



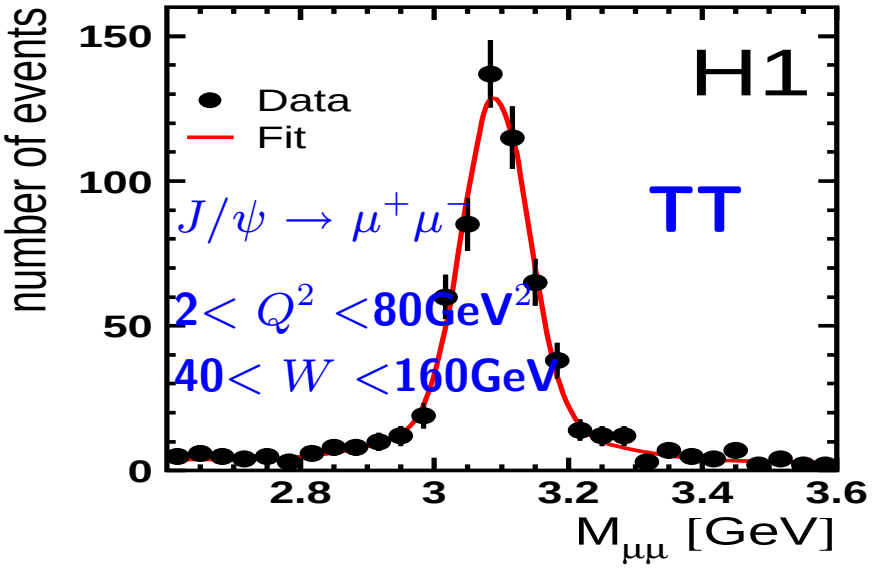
$J/\psi \rightarrow e^+e^-$

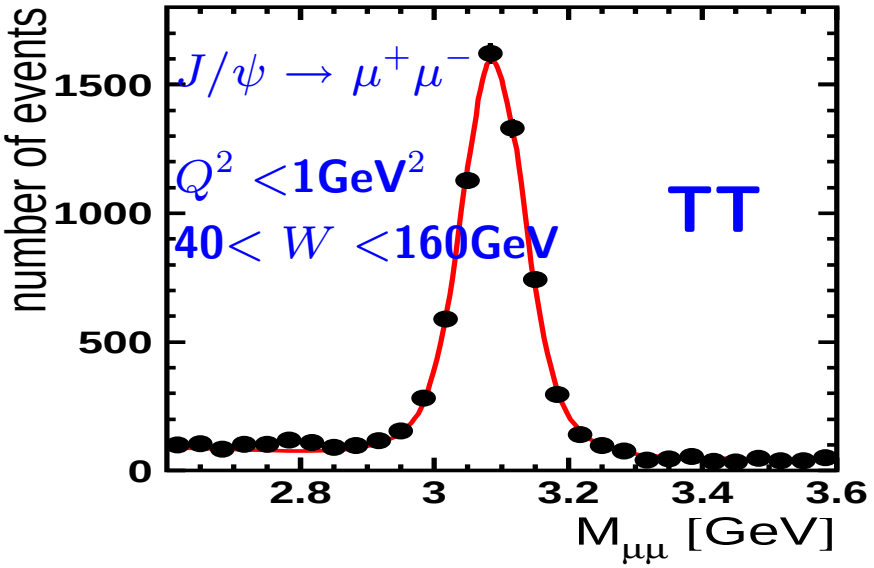
1 track
1 cluster

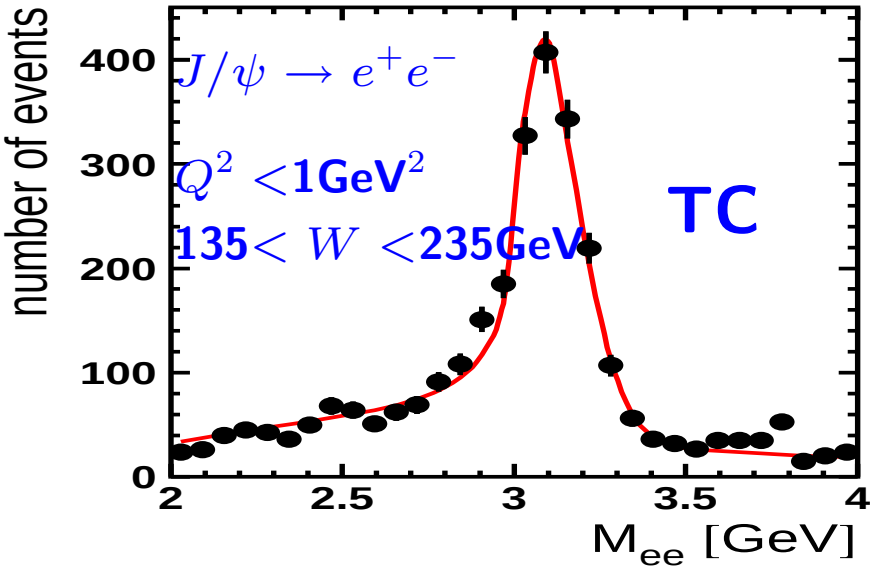
CC photoproduction

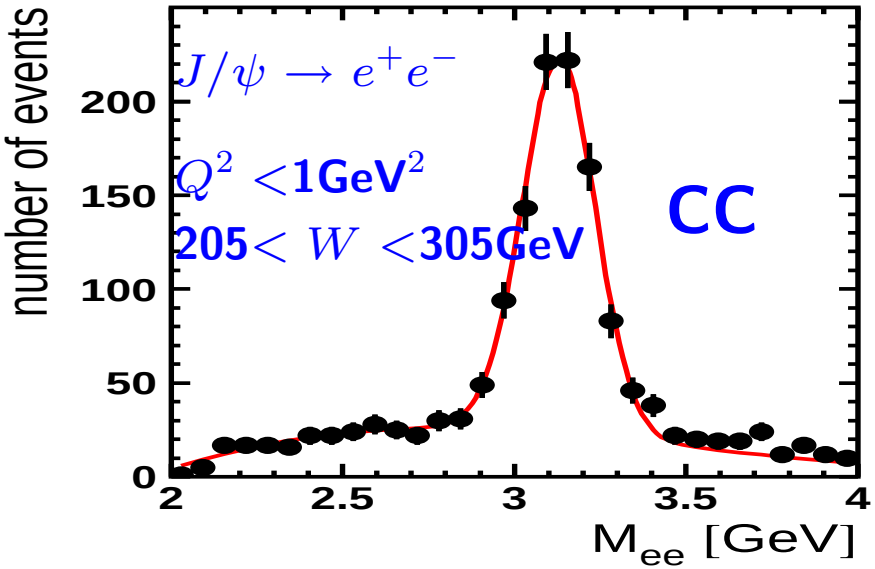


2 clusters


H1
Data
Fit
$J/\psi \to \mu^+\mu^-$
$2 < Q^2 < 80\,\mathrm{GeV}^2$
$40 < W < 160\,\mathrm{GeV}$
TT
number of events
$M_{\mu\mu}$ [GeV]


$J/\psi \to \mu^+\mu^-$
$Q^2 < 1\,\mathrm{GeV}^2$
$40 < W < 160\,\mathrm{GeV}$
TT
number of events
$M_{\mu\mu}$ [GeV]


$J/\psi \to e^+e^-$
$Q^2 < 1\,\mathrm{GeV}^2$
$135 < W < 235\,\mathrm{GeV}$
TC
number of events
M_{ee} [GeV]


$J/\psi \to e^+e^-$
$Q^2 < 1\,\mathrm{GeV}^2$
$205 < W < 305\,\mathrm{GeV}$
CC
number of events
M_{ee} [GeV]

Cross Section Determination

$$\sigma(\gamma p \to J/\psi p) = \frac{N_{notag}\cdot(1-f_{\psi(2S)})\cdot(1-f_{pdis})}{\epsilon\cdot BR\cdot\mathcal{L}\cdot\Phi_\gamma}$$

N_{notag}: the number of signal events without forward tag.

$f_{\psi(2S)}$: contamination from $\psi(2S)$

f_{pdis}: correction from proton dissociation

ϵ : total efficiency

BR : $BR(J/\psi \to \mu\mu) = (5.88 \pm 0.10)\%$

$BR(J/\psi \to ee) = (5.93 \pm 0.10)\%$

$\mathcal{L}$: luminosity

Φ_γ : integrated photon flux

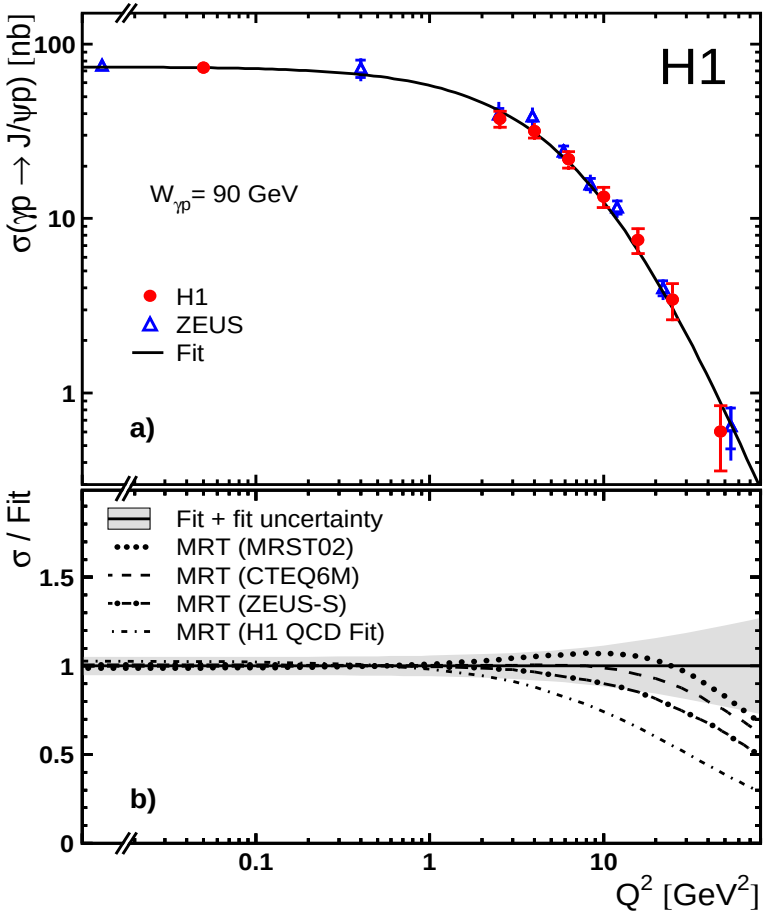
Systematic uncertainties:

- the track reconstruction efficiency
- the lepton identification efficiency
- the trigger efficiency
- the separation of elastic events from proton dissociation
- ......

The total systematic uncertainties on the cross section are 8% (TT in electroproduction), 9% (TT in photoproduction), 10% (TC) and 11% (CC), respectively.

Results

Q^2 Dependence



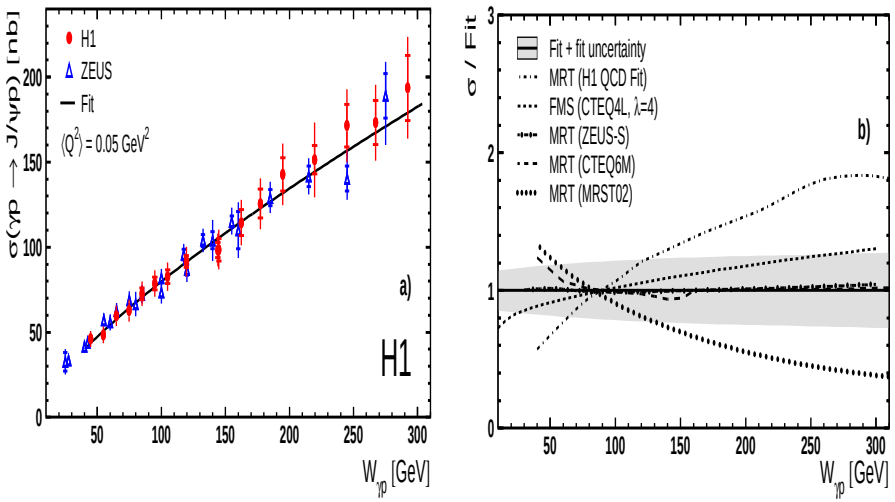
Fit: $\sigma \propto (M^2_{J/\psi} + Q^2)^{-n}$

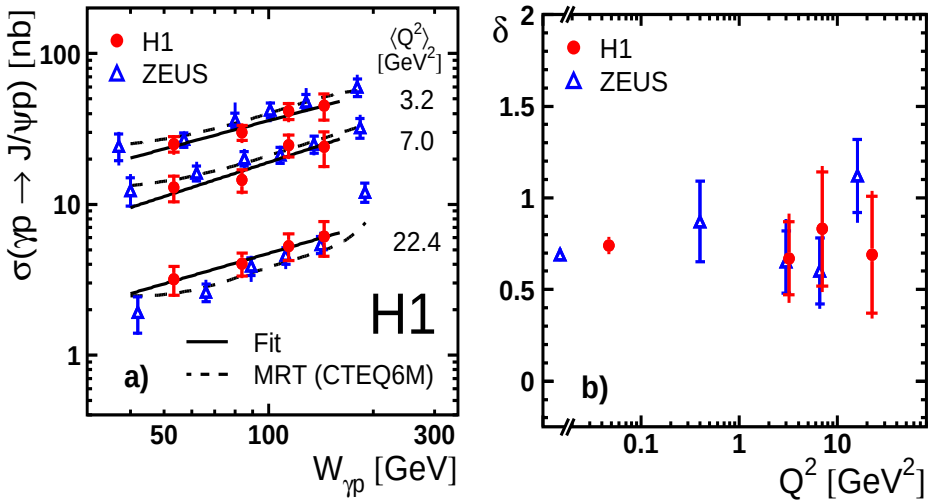
yields: $n = 2.486 \pm 0.080 \pm 0.068$

$$\chi^2/ndf = 0.5$$

- H1 and ZEUS: in good agreement
- At large Q^2, data sensitive to gluon distribution

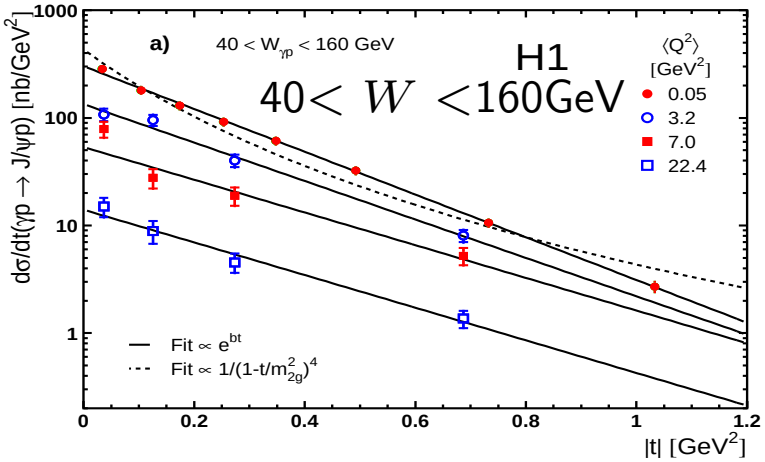
W Dependence

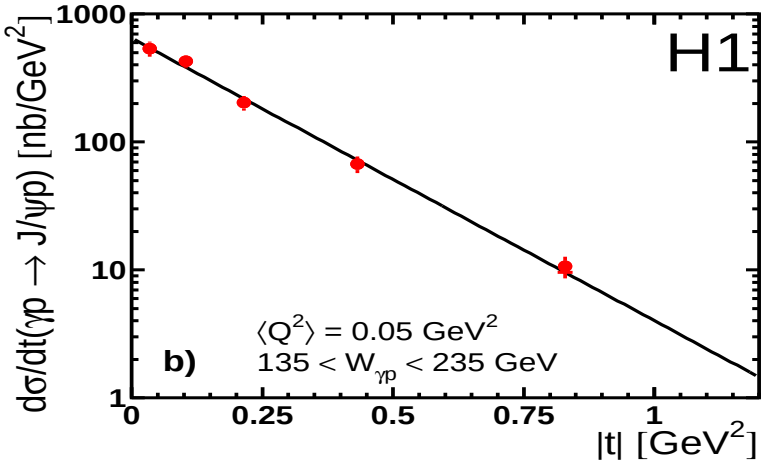


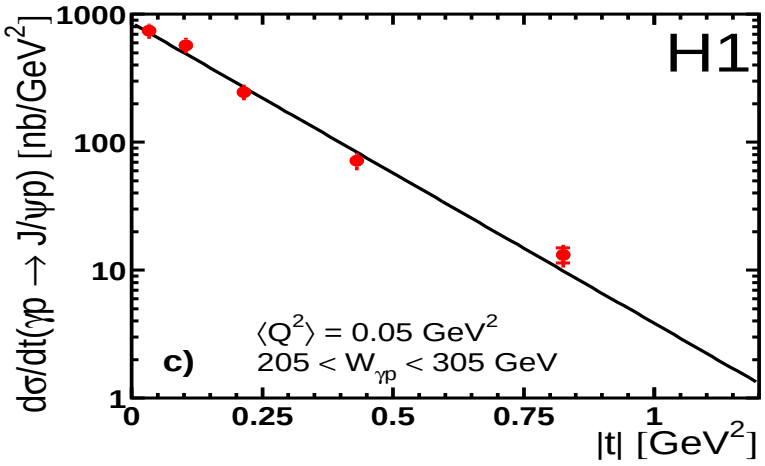


- $\sigma \propto W^{\delta}$
- photoproduction:($40 < W < 305$GeV)
  - δ: $\delta = 0.75 \pm 0.03 \pm 0.03$
    $\delta = 0.69 \pm 0.02 \pm 0.03$ (ZEUS)
  - pQCD calculations strongly depend on gluon distribution
- electroproduction: ($40 < W < 160$GeV)
  - The resulting δ is consistent with that in photoproduction
  - pQCD calculation based on CTEQ6M describe data
- No Q^2 dependence of δ is observed

t Dependence (photo- and electroproduction)







- Date well described by simple exponential

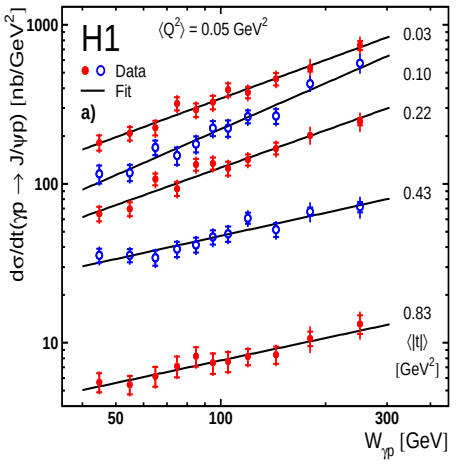
$$\frac{d\sigma}{dt} \propto e^{bt}; \qquad \chi^2/ndf = 0.25$$

- Dipole form disfavoured

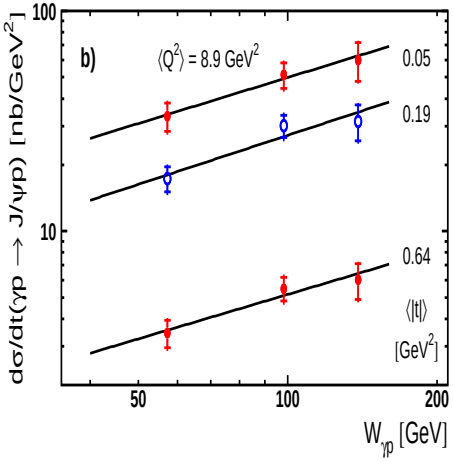
$$\frac{d\sigma}{dt} \propto (1-t/m_{2g}^2)^{-4}; \quad \chi^2/ndf = 5.5$$

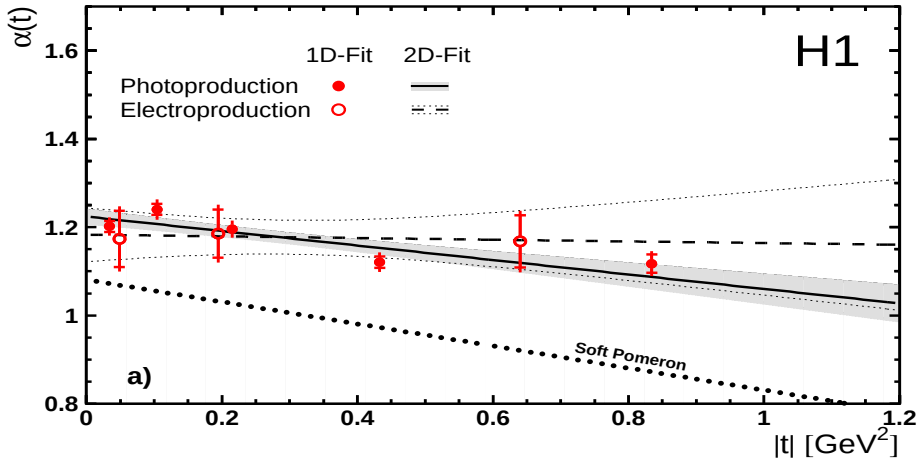
Effective Pomeron Trajectory $\alpha(t) = \alpha_0 + \alpha' \cdot t$

photoproduction



electroproduction



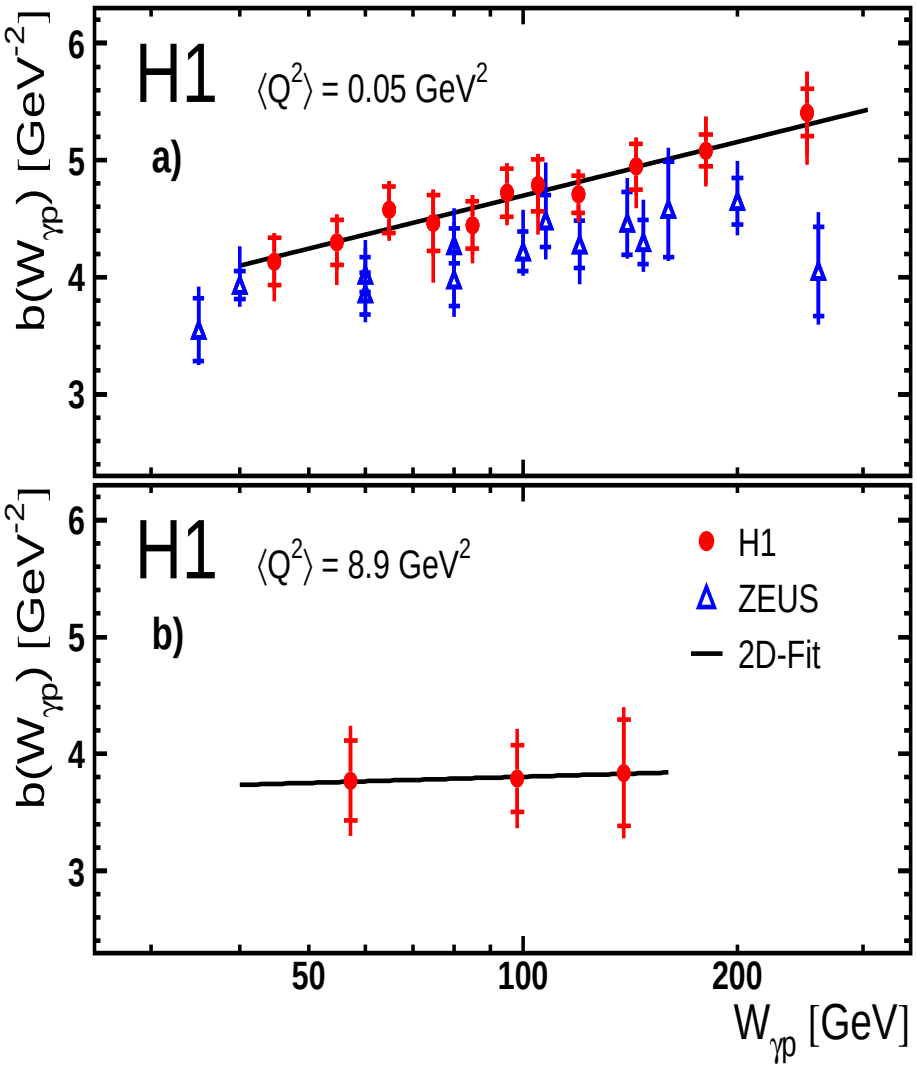


- One-dimensional fit:
  $\frac{d\sigma}{dt}(W) \propto W^{4(\alpha(<t>)-1)}$
  describe the data well
- Two-dimensional fit:
  $\frac{d\sigma}{dt} \propto e^{b_0 t}(\frac{W}{W_0})^{4(\alpha(t)-1)}$
  - photoproduction:
    $\alpha_0 = 1.224 \pm 0.010 \pm 0.012$
    $\alpha' = (0.164 \pm 0.028 \pm 0.030)$ GeV^{-2}
  - electroproduction:
    $\alpha_0 = 1.183 \pm 0.054 \pm 0.030$
    $\alpha' = (0.019 \pm 0.139 \pm 0.076)$ GeV^{-2}

Soft pomeron trajectory:

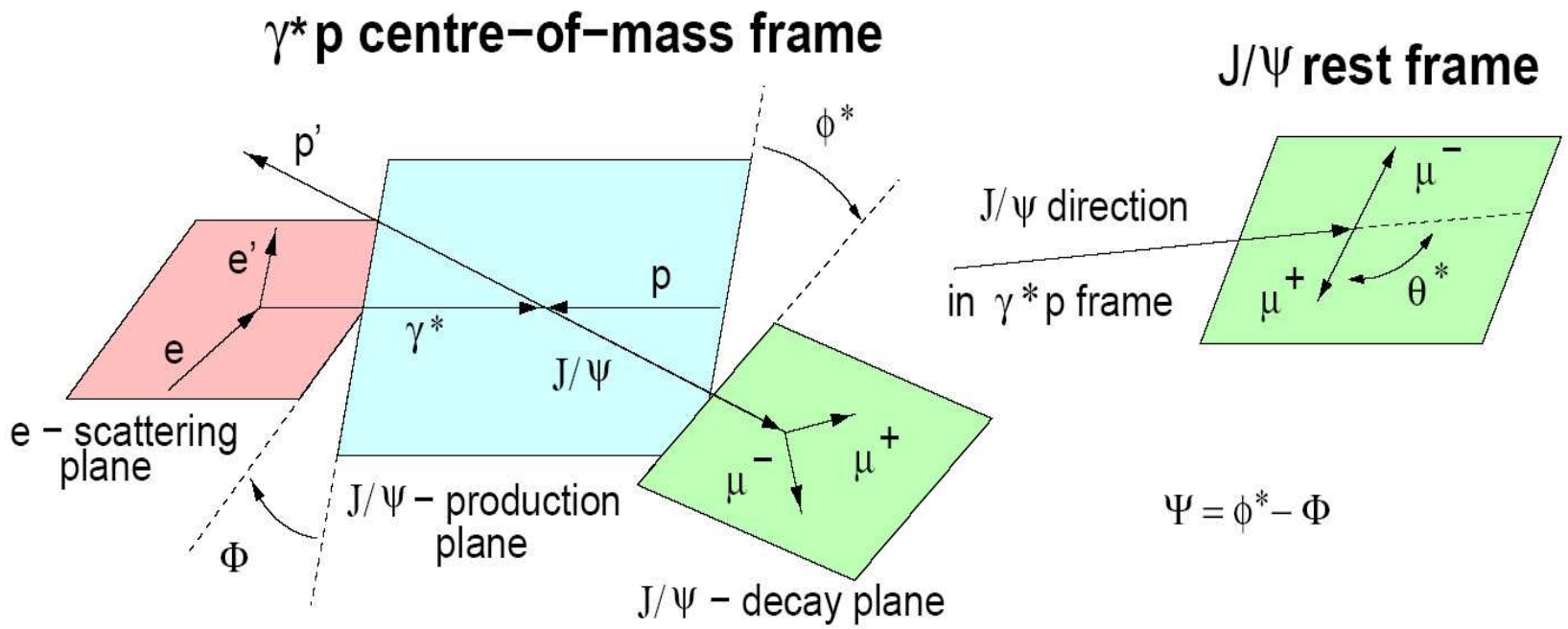
$\alpha(t) = 1.08 + 0.25$ Gev$^{-2}\cdot t$

Shrinkage

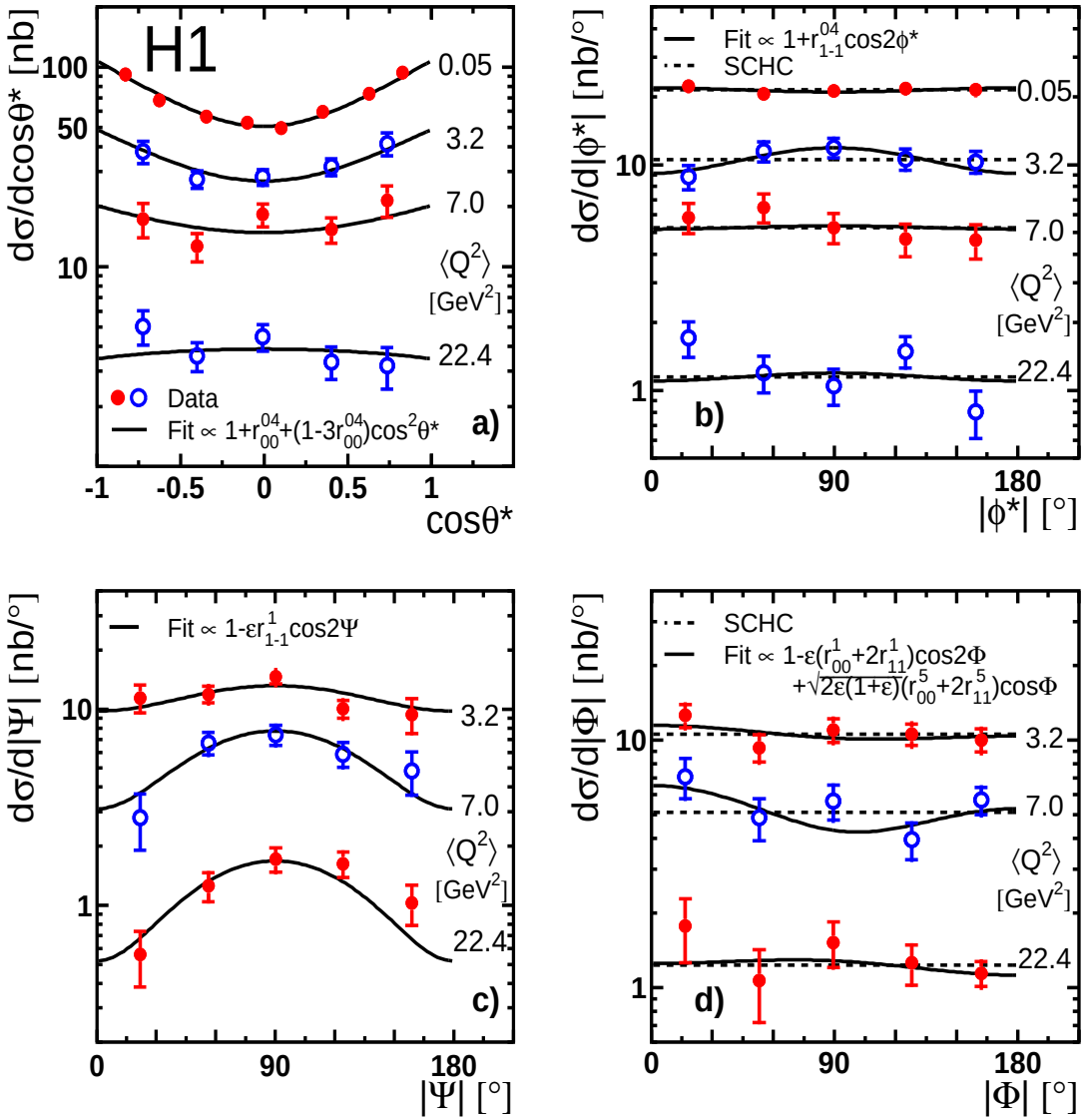


- One-dim. and two-dim. fit:
  one-dim. (data points):
  $$d\sigma/dt \propto e^{bt}$$
  two-dim. (lines):
  $$\frac{d\sigma}{dt} \propto e^{(b_0+4\alpha' ln(W/W_0))\cdot t}$$
- Similar W dependence of b seen from H1 and ZEUS
- Shrinkage seen in photoproduction
  the b values increase with W

Helicity Studies



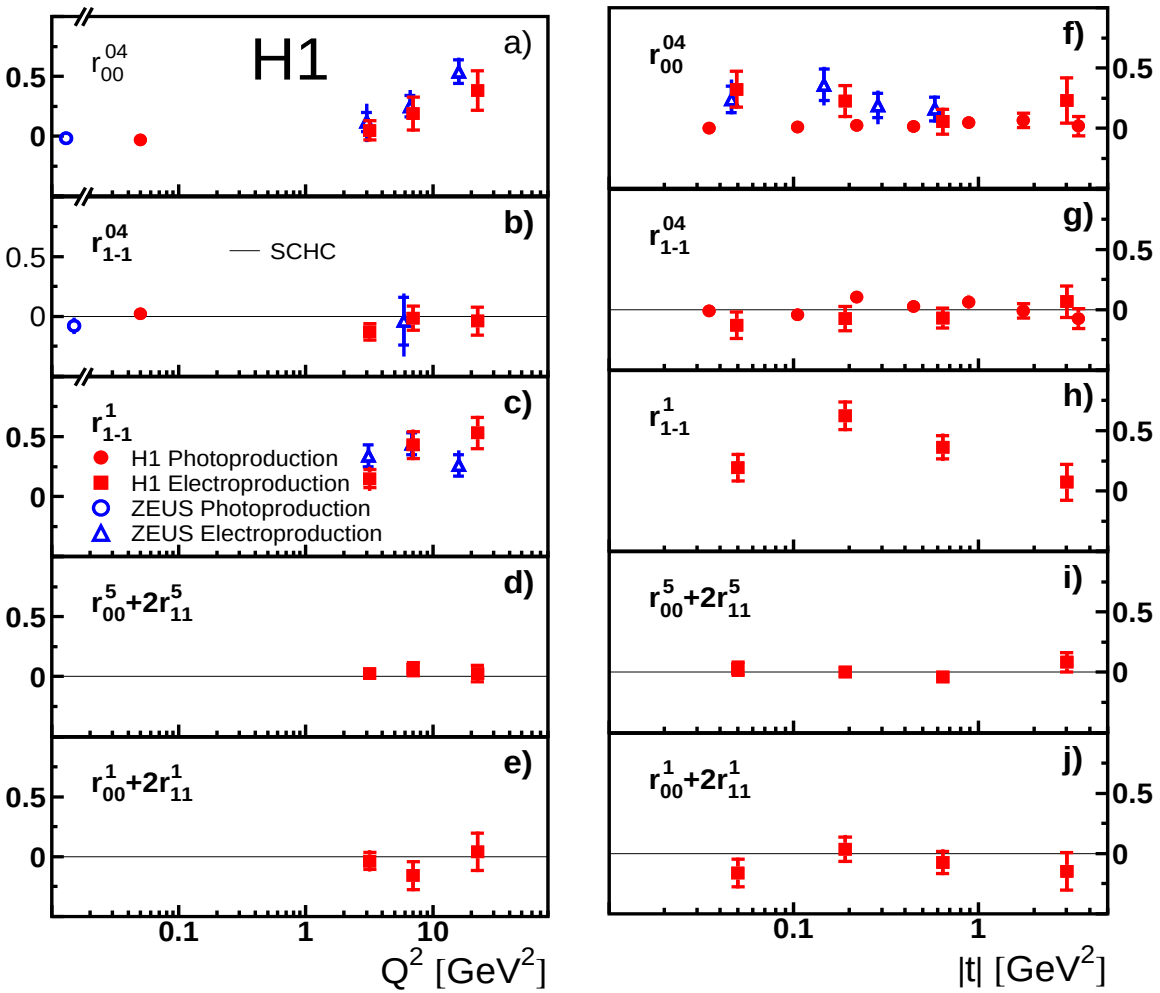
- SCHC: J/ψ keeps the helicity of the photon
- The SCHC can be tested by measurements of the angular distributions, θ^*, ϕ^*, Φ (Φ only measured in electroproduction)



solid line — fit to the data
dash line — SCHC prediction

- For ϕ^* and Φ, SCHC prediction is in agreement with data
- Extract the spin-density matrix elements by fitting the data

Spin-Density Matrix Elements



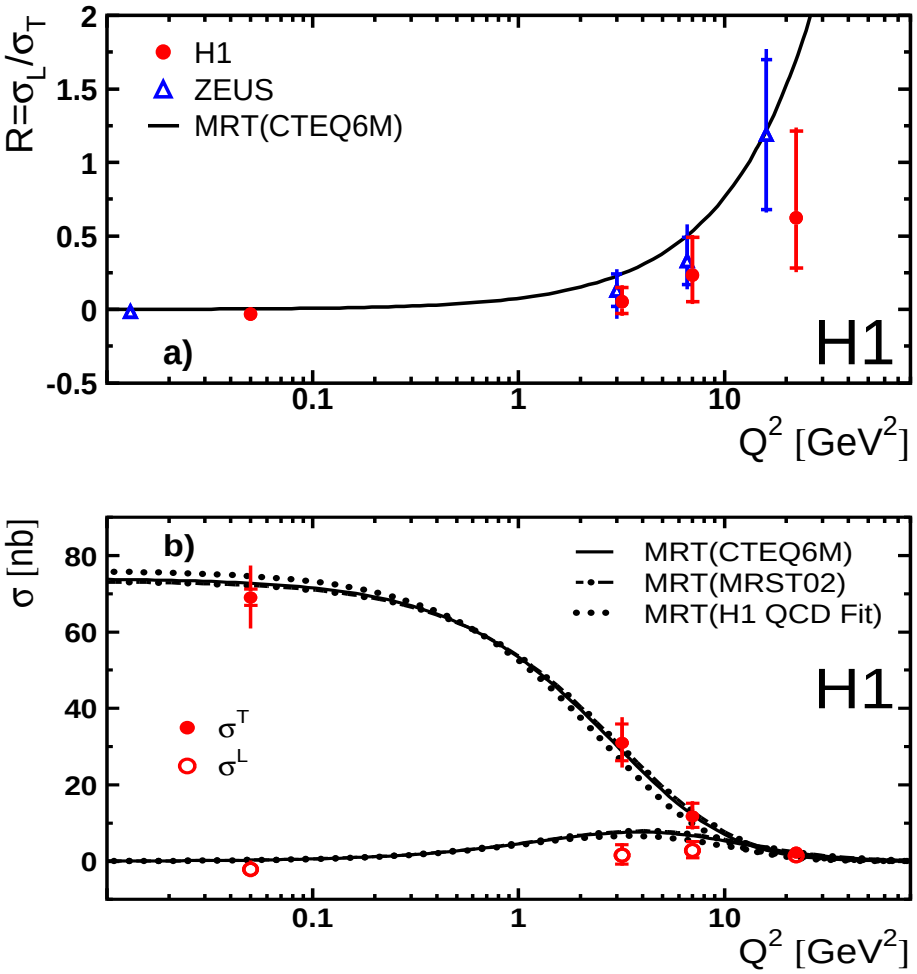
$\Longleftarrow$ Q^2 and t dependence of spin-density matrix elements

- No evidence for SCHC violation:
  r^{04}_{11}, $r^{5}_{00} + 2r^{5}_{11}$, and $r^{1}_{00} + 2r^{1}_{11}$ expected to be zero.
  $$r^{1}_{11} = (1 - r^{04}_{00})/2$$

- use r^{04}_{00} to extract σ_L and σ_T

Helicity studies show consistency with SCHC

Longitudinal and Transverse Cross Sections



- $R = \frac{\sigma_L}{\sigma_T} = \frac{r_{00}^{04}}{\epsilon \cdot (1 - r_{00}^{04})}$ $(\epsilon \approx 0.99)$

  H1 and ZEUS: agree well

- $\sigma_{\gamma p} = \sigma^T + \epsilon \cdot \sigma^L$

  σ^T dominates at low Q^2
  At large Q^2, $\sigma_L \sim \sigma_T$

- Data reasonably well described by MRT

Summary

Measurements of cross section for J/ψ photoproduction and electroproduction.

- Q^2 dependence: Data sensitive to gluon distribution at large Q^2.
- W dependence: No Q^2 dependence of δ.
  Described by pQCD.
  Data show a high sensitivity to the gluon density of the proton in low x and low Q^2.
- t dependence well described by a simple exponential function.
- Effective pomeron trajectories are determined.
- Shrinkage seen in photoproduction.
- Helicity studies: support SCHC.
  The ratio $R = \frac{\sigma_L}{\sigma_T}$ measured and described by pQCD.

backup slides

Summary of some most important event selection criteria

Period	1999 - 2000			
Date set	I	II	III	IV
Kinematic region	Electroproduction	Photoproduction		
Q^2 range [GeV^2]	2-80	< 1		
$< Q^2 >$ [GeV^2]	8.9	0.05		
$W_{\gamma p}$ [GeV]	40-160		135-235	205-305
$\|t\|$ [GeV^2]	< 1.2			
Decay channel	$J/\psi \to \mu^+\mu^-$		$J/\psi \to e^+e^-$	
Lepton signature	Track-Track		Track-Cluster	Cluster-Cluster
trigger	s15,s61	s15,s54	s33	s40
Lepton polar angle [^{o}]	20-160		θ_1: 80-155 θ_2: 160-177	θ_1: 160-174 θ_2:160-175.5
Lepton energy [GeV]	$p_t > 0.8$		$p_{t1} > 0.7$,$p_1 > 0.8$ $E_2 > 4.2$	$E_{1,2} > 4.2$ $max(E1, E2) > 6$
Elastic selection	No signal in forward detectors			
$\int \mathcal{L}$ dt [pb^{-1}]	54.79		30.26	26.90

W dependence:

Data set	Q^2[GeV^2]	$< Q^2 >$[GeV^2]	δ
TT	<1	0.05	$0.75 \pm 0.03 \pm 0.03$
TT	2-5	3.2	$0.67 \pm 0.20 \pm 0.14$
	5-10	7.0	$0.83 \pm 0.31 \pm 0.15$
	10-80	22.4	$0.69 \pm 0.32 \pm 0.14$

Table 1: The parameters δ ($\sigma \propto W^{\delta}$) measured in bins of Q^2 in the range $40 < W < 160$GeV and $|t|$ <1.2GeV^2. The values $< Q^2 >$ indicate the bin centre value in the Q^2 range considered. The first error is statistical and the second systematic.

t dependence:

Data set	$< Q^2 >$[GeV^2]	W[GeV]	b[GeV^{-2}]
TT	0.05	40-160	$4.57 \pm 0.06^{+0.11}_{-0.18}$
TT	3.2	40-160	$4.11 \pm 0.26 \pm 0.37$
	7.0		$3.50 \pm 0.50 \pm 0.49$
	22.4		$3.49 \pm 0.45 \pm 0.33$

Data set	$< Q^2 >$[GeV^2]	W[GeV]	b[GeV^{-2}]
TC	0.05	135-235	$5.08 \pm 0.14^{+0.25}_{-0.27}$
CC	0.05	205-305	$5.41 \pm 0.20^{+0.29}_{-0.40}$

Table 2: The slope parameters b derived from $\frac{d\sigma}{dt} \propto e^{-b|t|}$ in photoproduction and electroproduction. The values $< Q^2 >$ indicate the bin centre value in the Q^2 range considered. The first error is statistical and the second systematic.